Interception of wet deposited and transfers of radiocaesium and radiostrontium by *Bríssica napus* L. and *Tríticum aestívum* L.*

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Abstract. The aim of this study is to assess the interception and transfer to edible part of wet deposited ^{134}Cs and ^{85}Sr to spring oilseed rape and spring wheat and the dependency of the intercepted fraction on the development stage *e.g.* the total plant biomass. The radionuclides, ^{134}Cs and ^{85}Sr, were deposited at six different development stages using a rainfall simulator. The results showed that there was a positive correlation between the interception fraction for ^{134}Cs and ^{85}Sr and the biomass both for spring oilseed rape and spring wheat. The interception fraction and transfer factors were highest at growing stage of senescence (ripening) for both crops.

1. INTRODUCTION

The release of radionuclides to the atmosphere by different processes leads to air-borne contamination of the vegetation [1, 2]. Some of these deposited radionuclides, *e.g.* radiocaesium and radiostrontium, are taken up by the vegetation directly through leaves. There is limited information on the direct uptake rate of radionuclides and as well the rate of intercepted radionuclides by plants, directly after the occurrence of wet deposition in a growing crop [3]. The level of interception by plant parts depends on climate conditions like precipitation, wind speed, physico-chemical form of the radionuclides, plant morphology and biomass density [3, 4, 5]. The proportion of precipitation that can be held by the plant canopy is quickly declining after that the maximum holding capacity of leaves have been reached, which is related to the amount and intensity of the precipitation as well as the plant morphology *i.e.* Leaf Area Index (LAI), the angel of the leaves and biomass [2, 6]. After the maximum water retention capacity of the leaves is reached, the concentration of radioactive particles may continue to increase due to their physico-chemical properties, *e.g.* valence; the divalent radiostrontium ion is easily fixe to the surface of leaves [2, 4]. The time between depositions and harvest also has an effect on the total uptake of radionuclides in plants. This depends on ‘field losses’ and has been further described by Chadwick and Chamberlain (1970) [7]. The cuticle layers of leaves are rather resistant to penetration of radionuclides, instead radionuclides enter the plant through cracks and defects of the cuticle

* The current investigation is a part of a research project.

layers [8]. The aim of this research project was to study the interception in spring oilseed rape (*Brássica napus* L.) and spring wheat (*Tríticum aestívum* L.) of ^{134}Cs and ^{85}Sr wet deposited at different growth stages and to calculate transfer factors (concentrations of radionuclides in edible plant parts *i.e.* seeds and grains in relation to deposited amounts).

2. MATERIALS AND METHODS

2.1 Design of the experiment

The study was conducted at an agricultural field station at Ultuna, Sweden (59°48'45"N and 17°38'45"E) during the summer 2010. The trial had randomized block design with three replicates with 1 × 1 m parcels. The experiment crops were winter wheat and oil seed rape sown and grown according to common agricultural practices. The radionuclides ^{134}Cs and ^{85}Sr were supplied with artificial rain at six different plant growth stages (see below). The rain simulator used was a modified version of the drip infiltrometer described by Joel and Messing (2001) [9]. The amount of precipitation applied was 1 mm. The applied amounts of ^{134}Cs were in the range from 27 to 31 kBq m^{-2} and of ^{85}Sr from 39 to 49 kBq m^{-2}. The growth stages when deposition was performed were: 1) leaf development (3 leafs unfold), 2) leaf development (9 or more leafs unfold), 3) 10% of flowers on main raceme open, 4) full flowering, 5) beginning of ripening and 6) senescence, for spring oilseed rape. For the spring wheat the growth stages were: 1) tillering (headshot and 1 side shot), 2) stem extension (flag leaf visible), 3) flowering (on-going flowering), 4) ripening (dough ripeness) and the two last at ripening ((5) ripe for cutting, (6) straw dead). Fertilizer was applied in an amount corresponding to 104 kg N ha^{-1} and 19 kg P ha^{-1}; no K was added due to high natural content of K in the clay soil.

2.2 Sampling and analyses

Plant sampling was made 2 - 3 hours after deposition in a 25 × 25 cm square area in the middle of each parcel. Whole plants were sampled but at the last sampling seed or grains were separated from the rest of the plant. The plants materials were weighed for fresh weight, air dried (30°C), re-weighed for dry weight and then milled before measurement of radioactivity concentration. Milled samples were placed in 35 mL or 60 mL plastic jars with a suitable geometry for the measurement. Measurements were made with High-Purity Germanium (HPGe) detectors. All activity concentrations were expressed as Bq kg^{-1} dry weight and decay corrected to the sampling date. Statistical analyses performed were paired t-test and regression analysis.

2.3 Calculations

The interception of radionuclides was expressed as the interception fraction, *f*, according to equation 1 modified after Pröhl (2009) [10]. The interception fraction is the ratio between the activity in the dry weight biomass of plant directly after deposition (A_i, Bq m^{-2}) and the total amount of activity deposited (A_t, Bq m^{-2}) multiplied by 100 to convert to percentage:

$$f = \frac{A_i}{A_t} \times 100 \qquad (1)$$

The concentration of radionuclides in the edible plant parts (*i.e.* seeds and grains) in relation to the size of deposition was calculated as the transfer factor, TF (m^2 kg$^-$

^{1}), the ratio between the total activity in seed or grain at sampling (A_c, Bq kg^{-2}) and the amount of activity deposited (A_t, Bq m^{-2}) (Equation 2) [11].

$$TF = \frac{A_c}{A_t} \tag{2}$$

3. RESULTS

3.1 Interception fraction and transfer factor of ^{134}Cs and ^{85}Sr

The intercepted fraction of ^{134}Cs and ^{85}Sr increased with biomass density and was positively correlated to the crop biomass of both crops (Figure 1).

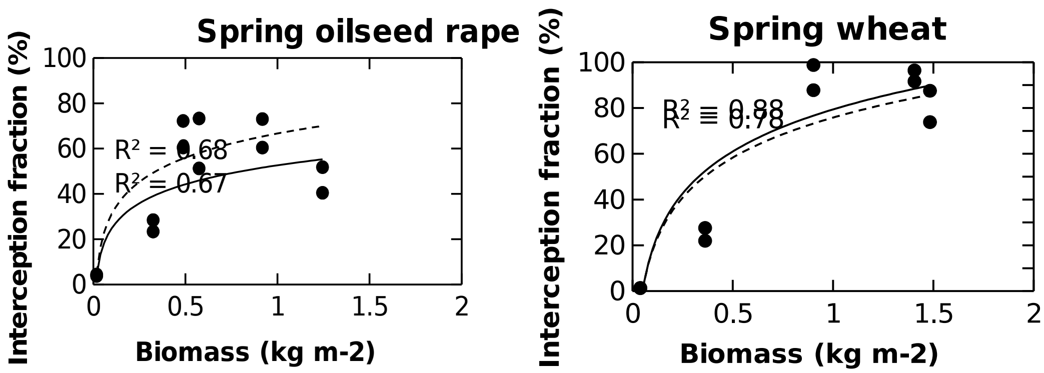

Figure 1. Relationship between intercepted fraction of ^{134}Cs (●) (–) and ^{85}Sr (○) (--) and biomass (kg m^{-2}) of spring oilseed rape and spring wheat. Mean values fitted to a logarithmic function.

The mean intercepted fractions were significantly higher for ^{134}Cs than for ^{85}Sr in spring oilseed rape plants ($p = 0.02$). For spring wheat there was no significantly difference ($p = 0.55$). The transfer factors were significantly higher for ^{134}Cs than for ^{85}Sr in spring oilseed rape seeds ($p = 0.03$), while for spring wheat grains there was no significant difference ($p = 0.17$). The highest transfer for both ^{134}Cs and ^{85}Sr in spring oilseed rape seeds occurred after deposition in the growth stage 'beginning of ripening'. In spring wheat grains the highest transfer for ^{134}Cs occurred after deposition in the growth stage at ripening (dough ripeness) and for ^{85}Sr at the growth stage at ripening (ripe for cutting, straw dead). Transfers were higher for ^{134}Cs than for ^{85}Sr in both crops. Spring oilseed rape seeds had higher transfer factors for both radionuclides than spring wheat grains in the late development stages.

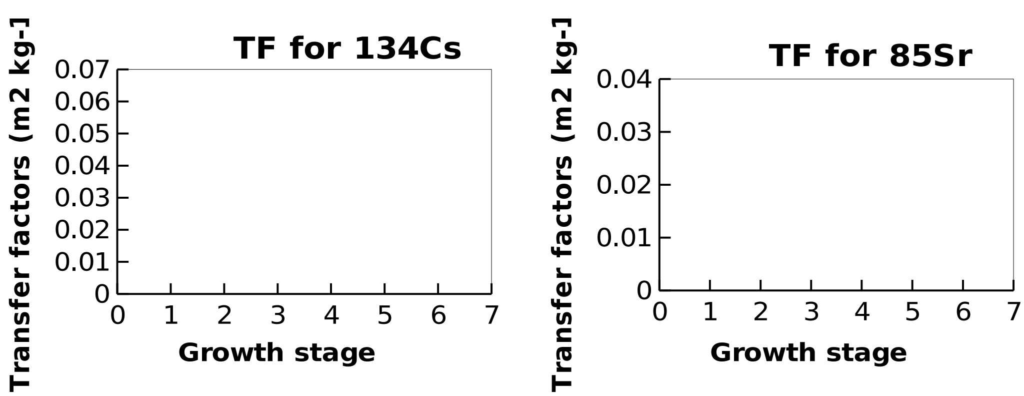

Figure 2. Mean values of transfer factors (TF) (m^2 kg^{-1}) for ^{134}Cs and ^{85}Sr in spring oilseed rape seeds (●) and spring wheat grains (○). Error bars show maximum and minimum values.

4. CONCLUSION

There was a positive correlation between the intercepted fraction of caesium and strontium radionuclides and the biomass of spring oilseed rape and spring wheat. The development stages of the crops are important for the interception of wet deposited radionuclides. Depositions in the growth stages with a high biomass give higher values on interception fraction of radionuclides. The biomass density can be used as a measurement of the plants development stages, which have an influence of the level on intercepted radionuclides by the plant. The time from deposition to sampling, of seed or grain, has influence on the transfer factors. Deposition of radionuclides close to harvest leads to higher transfer in edible plants part.

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